Preliminary Result of A_N Measurement in $p^{-}p^{-}$ Elastic Scattering at RHIC, at Ö s = 200 GeV

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OUTLINE of the TALK

- Description of the experiment
- Comparison of run 2002 vs 2003
- Description of analysis
- Results and interpretation
- Where do we go from here?

Total and Differential Cross Sections, and Polarization Effects in pp Elastic Scattering at RHIC

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Spin Dependence in Elastic Scattering

Five helicity amplitudes describe proton-proton elastic scattering

$$F_1(s,t) \propto \langle ++|M|++\rangle$$
$$F_2(s,t) \propto \langle ++|M|--\rangle$$
$$F_3(s,t) \propto \langle +-|M|+-\rangle$$
$$F_4(s,t) \propto \langle +-|M|-+\rangle$$
$$F_5(s,t) \propto \langle ++|M|+-\rangle$$

$$F_{\mathbf{j}}(s,t) \propto \langle h_3\, h_4\, |M| h_1\, h_2 \rangle$$
$$= F^{em}{}_{\mathbf{j}}(s,t) + F^{had}{}_{\mathbf{j}}(s,t)$$

with h_x = s-channel helicity

$$F_+(s,t) = ½\,(F_1(s,t) + F_3(s,t))$$

Measure:

$$s_{tot} = \frac{8\,p}{s}\, \mathrm{Im}\,[\,F_+(s,t)\,]_{t=0}$$

$$\frac{ds}{dt} = \frac{2\,p}{s^2}\,\left(|F_1|^2 + |F_2|^2 + |F_3|^2 + |F_4|^2| + 4|F_5|^2\right)$$

$$?\,s_T = -\frac{8\,p}{s}\, \mathrm{Im}\,[\,F_2(s,t)\,]_{t=0} = s^{\uparrow\downarrow} - s^{\uparrow\uparrow}$$

$$?\,s_L = \frac{8\,p}{s}\, \mathrm{Im}\,[\,F_1(s,t) - F_3(s,t)\,]_{t=0} = s^{\rightleftarrows} - s^{\rightrightarrows}$$

Source of single spin analyzing power A_N

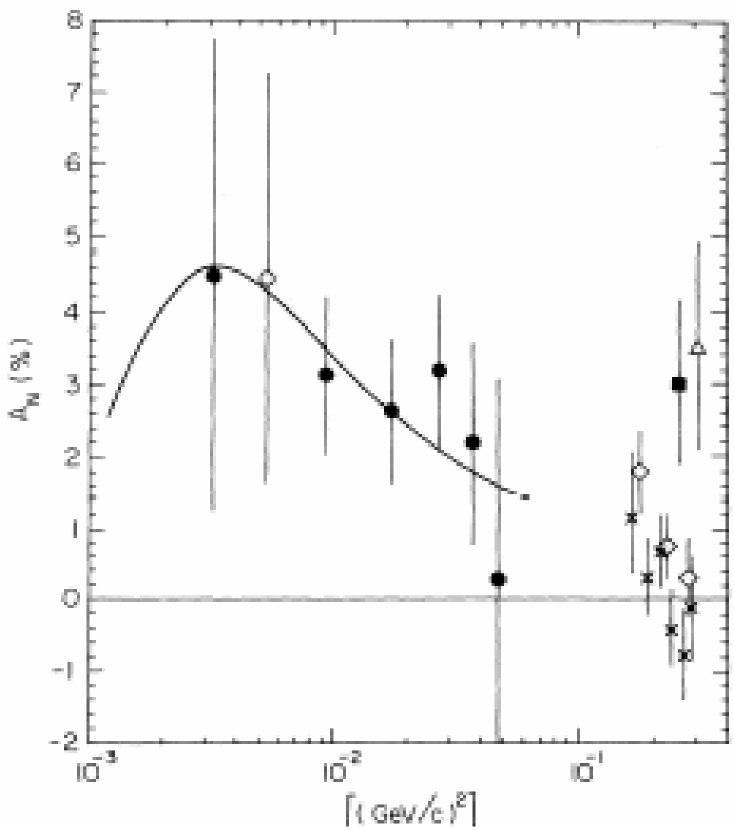
Single spin asymmetry A_N arises in the CNI region is due to the interference of hadronic non-flip amplitude with electromagnetic spin-flip amplitude (originally called Schwinger asymmetry)

Any difference from the above is an indication if other contributions, hadronic spin flip caused by resonance (Reggeon) or vacuum exchange (Pomeron) contributions.

$$A_N(t, j) = \frac{1}{P_{Beam}\cos j} \frac{N^{\uparrow\uparrow}(t) + N^{\uparrow\downarrow}(t) - N^{\downarrow\downarrow}(t) - N^{\downarrow\uparrow}(t)}{N^{\uparrow\uparrow}(t) + N^{\uparrow\downarrow}(t) + N^{\downarrow\downarrow}(t) + N^{\downarrow\uparrow}(t)} \propto \frac{\mathrm{Im}[j_5^* \Phi_+]}{ds/dt}$$

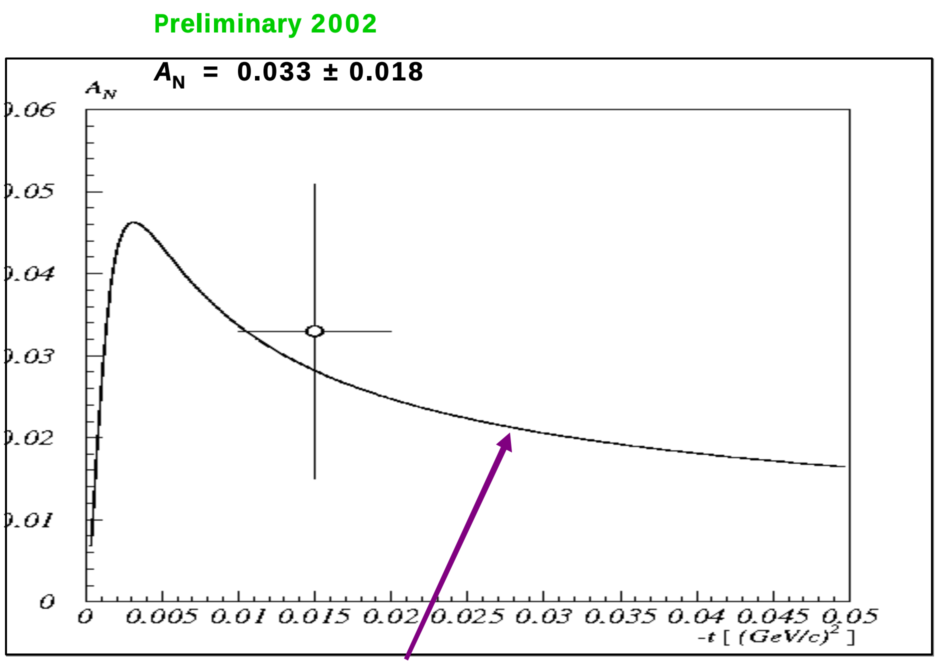
$$\boldsymbol{r_5 = R_5 + iI_5} = \frac{\boldsymbol{m f_5}}{\sqrt{\boldsymbol{-t}}\,\mathbf{Im}\boldsymbol{f_+}}$$

The world data (HE pp)



FNAL E704 • √s ≈ 20 GeV

N. Akchurin *et al*. PRD 48, 3026 (1993)



CNI curve

N.H. Buttimore *et al.* PRD 59,114010 (1999)

Experimental Determination of A_N

Use *Square-Root-Formula* to calculate spin (- - , ‾‾) and false asymmetries (- ‾ , ‾ - .)

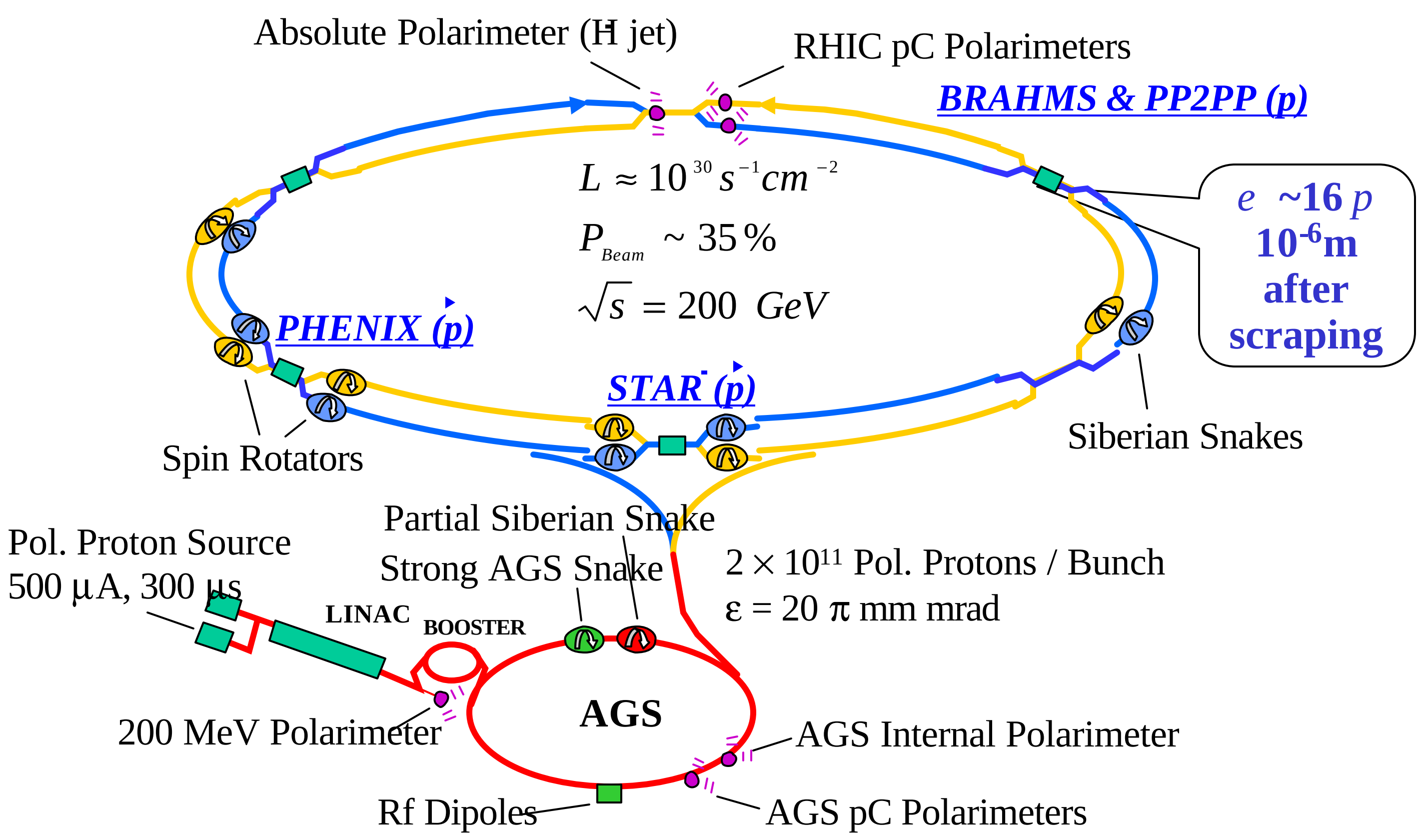
This formula cancels luminosity dependence.

$$A_N(j) = \frac{1}{(P_1 + P_2)\cos j} \frac{\sqrt{N_L^{--} N_R^{\overline{\ }\overline{\ }}} - \sqrt{N_R^{--} N_L^{\overline{\ }\overline{\ }}}}{\sqrt{N_L^{--} N_R^{\overline{\ }\overline{\ }}} + \sqrt{N_R^{--} N_L^{\overline{\ }\overline{\ }}}}$$

$$A_N(j) = \frac{1}{(P_1 + P_2)\cos j} \frac{\sqrt{N_L^{-\overline{\ }} N_R^{\overline{\ }-}} - \sqrt{N_R^{-\overline{\ }} N_L^{\overline{\ }-}}}{\sqrt{N_L^{-\overline{\ }} N_R^{\overline{\ }-}} + \sqrt{N_R^{-\overline{\ }} N_L^{\overline{\ }-}}}$$

Since A_N is a relative measurement the efficiencies $\varepsilon(t, \phi)$ cancel

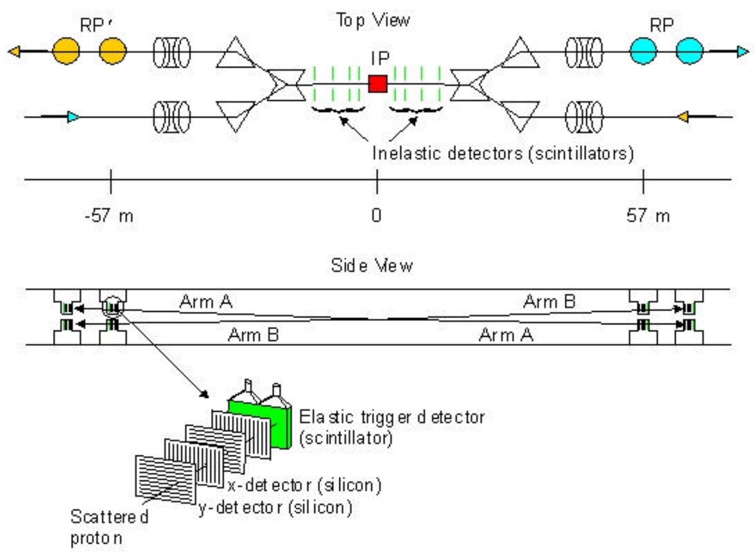
Polarized Proton Collisions in RHIC



Comparison Run 2002 and 2003

<table>
<tr><th></th><th>Engineering 2002</th><th>2003</th></tr>
<tr><td>Number of RP stations</td><td>2</td><td>4</td></tr>
<tr><td>Number of Si planes</td><td>16</td><td>32</td></tr>
<tr><td>Number of elastic events</td><td>$3 \cdot 10^5$</td><td>$1.3 \cdot 10^6$</td></tr>
<tr><td>Beam momentum</td><td colspan="2">100 GeV</td></tr>
<tr><td>Number of bunches</td><td colspan="2">55</td></tr>
<tr><td>b^*</td><td colspan="2">10 m</td></tr>
<tr><td>Beam emittence e [mm mrad]</td><td>12</td><td>16, 18</td></tr>
<tr><td>|t|-range</td><td colspan="2">$0.004\text{-}0.035\ (\mathrm{GeV}/c)^2$</td></tr>
<tr><td>Proton intensity</td><td>$5 \cdot 10^{11}$</td><td>$19 \cdot 10^{11}$</td></tr>
<tr><td>Proton beam polarization (estimate)</td><td>0.24</td><td>0.34</td></tr>
</table>

Principle of the Measurement



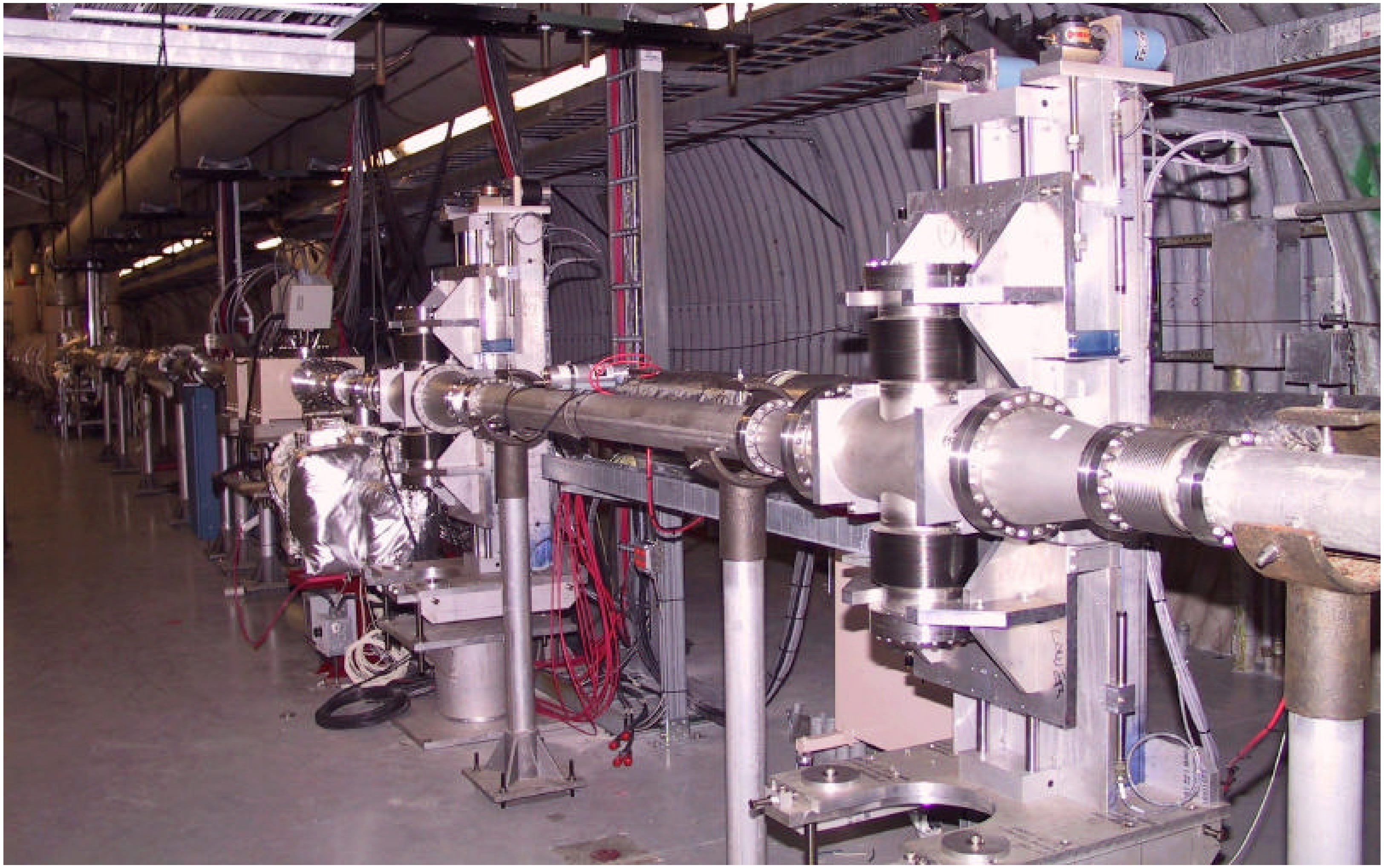
- Elastically scattered protons have very small scattering angle ? *, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without breaking accelerator vacuum

Beam transport equations **relate measured position at the detector to scattering angle**.

$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{pmatrix}$$

x_0,y_0: Position at Interaction Point
T^*_x T^*_y : Scattering Angle at IP
x_D, y_D : Position at Detector
T^x_D, T^y_D : Angle at Detector

The pp2pp Experimental Setup

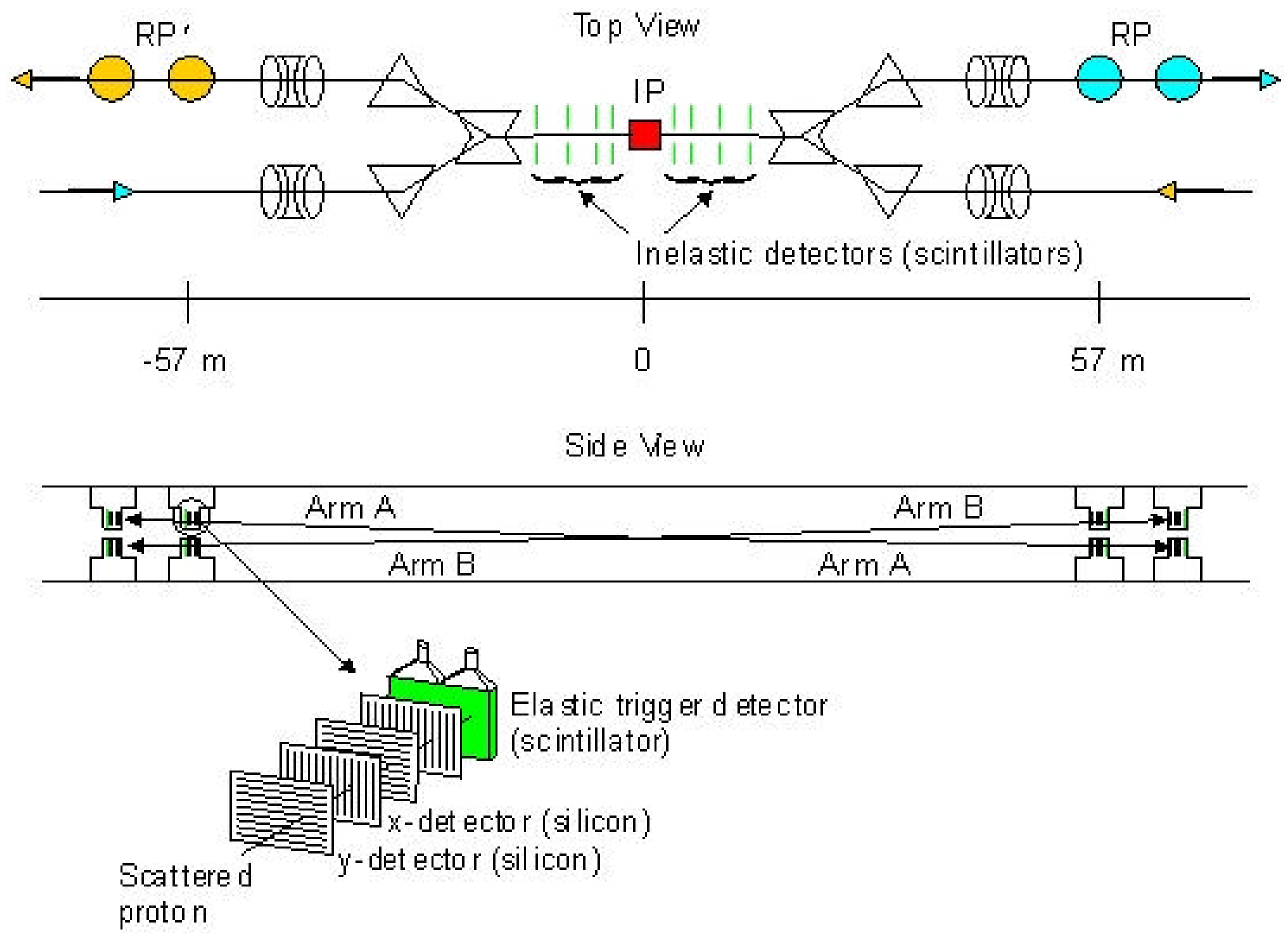


Spin Discussion Seminar
BNL, Aug. 31, 2004

Wlodek Guryn
for pp2pp collaboration

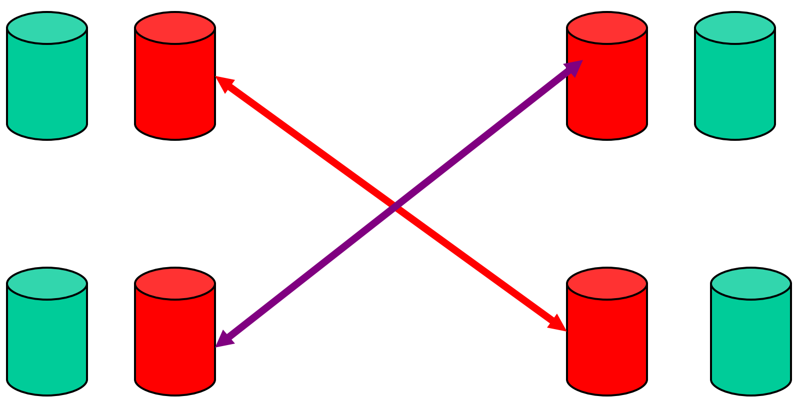
BROOKHAVEN NATIONAL LABORATORY

The Setup

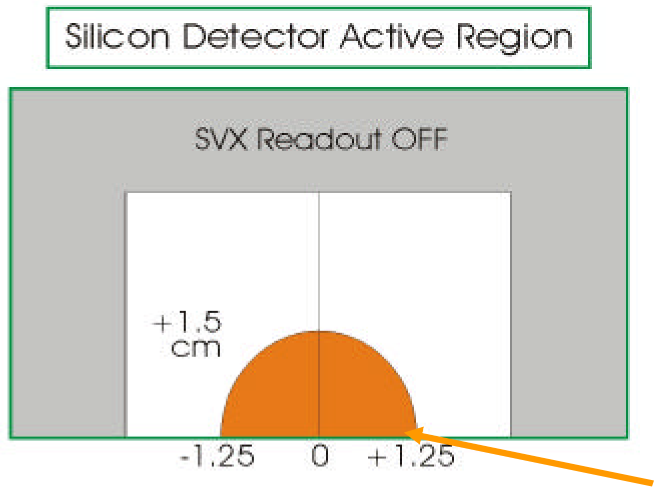


Top View
RP
RP
IP
Inelastic detectors (scintillators)
-57 m
0
57 m
Side View
Arm A
Arm B
Arm B
Arm A
Elastic trigger detector
(scintillator)
x-detector (silicon)
y-detector (silicon)
Scattered
proton

Trigger



Active area



Acceptance beam
pipe shadow

Only “inner” pots used for trigger and analysis, biggest acceptance

Analyze the data for the closest position (¾ of all data)

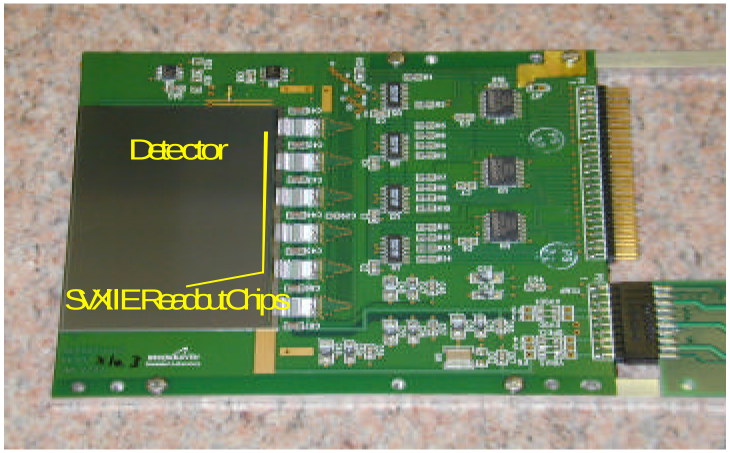
Si detectors

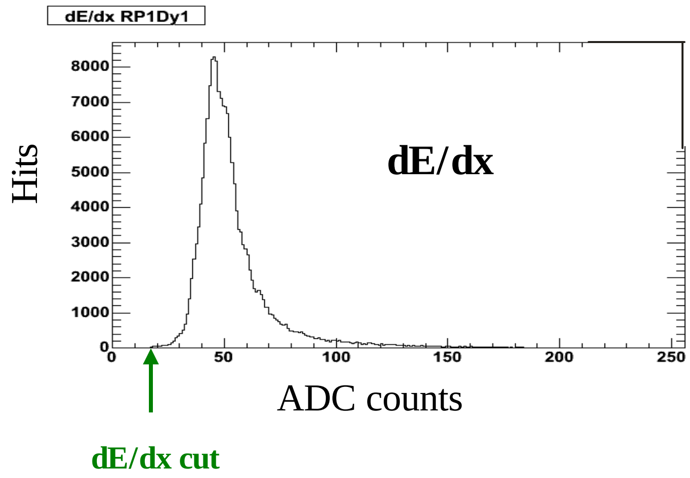
•100 GeV proton deposits (most probable value) 118 keV (» 32,000 e$^-$) in 400 um of silicon

•S/N ratio » 22 (measured)

•32 Si planes had average efficiency > 99.9% !!

X-View Detector Boa





•32 Hamamatsu Silicon Strip Detectors-2003 Run
- AC-coupled, Polysilicon Resistors
- Dual purpose guard/bias ring minimizes inactive area

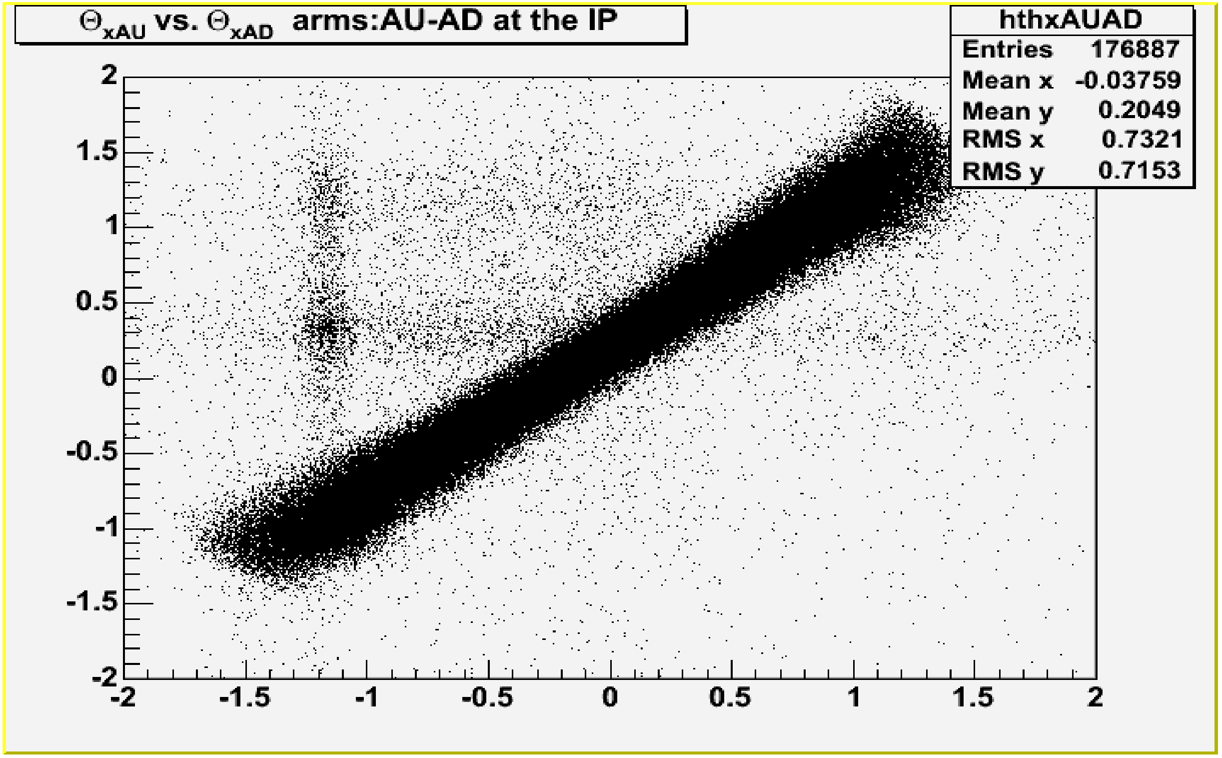
•Two detector types
- X-View: Vertical strips , Y-view: Horizontal strips

•74 x 45 mm^2 active area, 400 um thick

•Integrated Fan-in connects 100 um pitch strips to 48 um pitch readout

Angle (hit) Correlations Before the Cuts

Note: the background appears enhanced because of the "saturation" of the main band

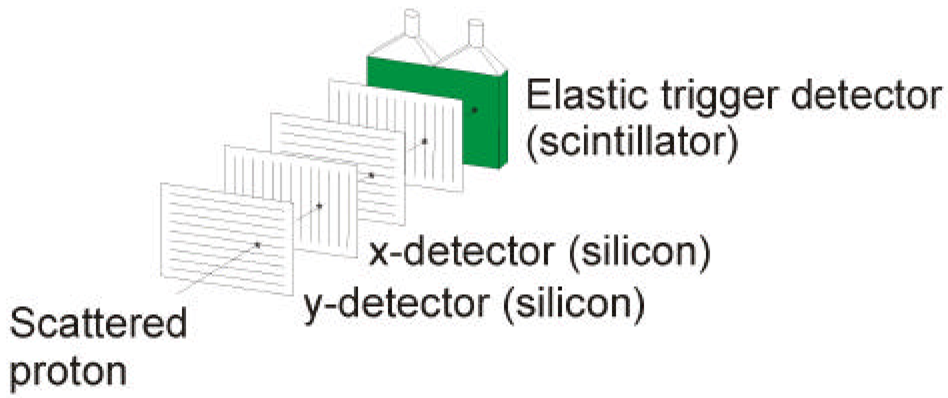


Elastic Evenet Identification

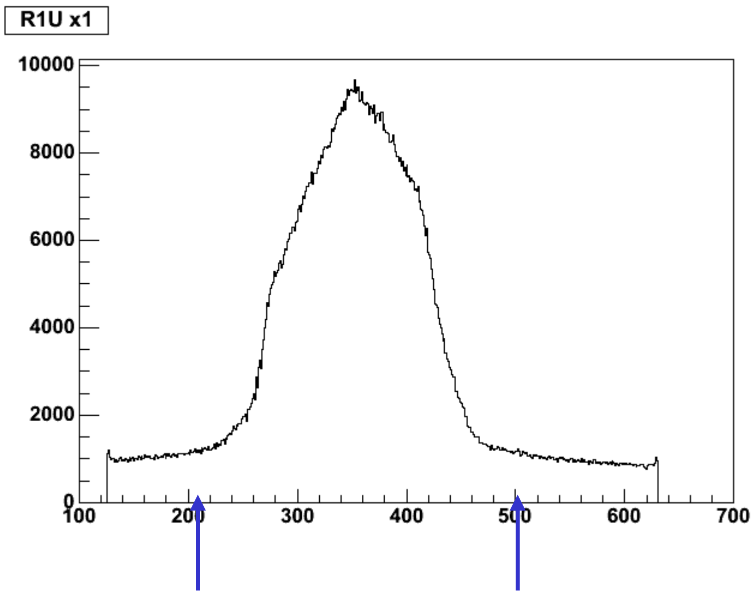
Adjacent planes

Find hits in the adjacent planes in the Roman Pot (x_1,x_2) and (y_1,y_2)

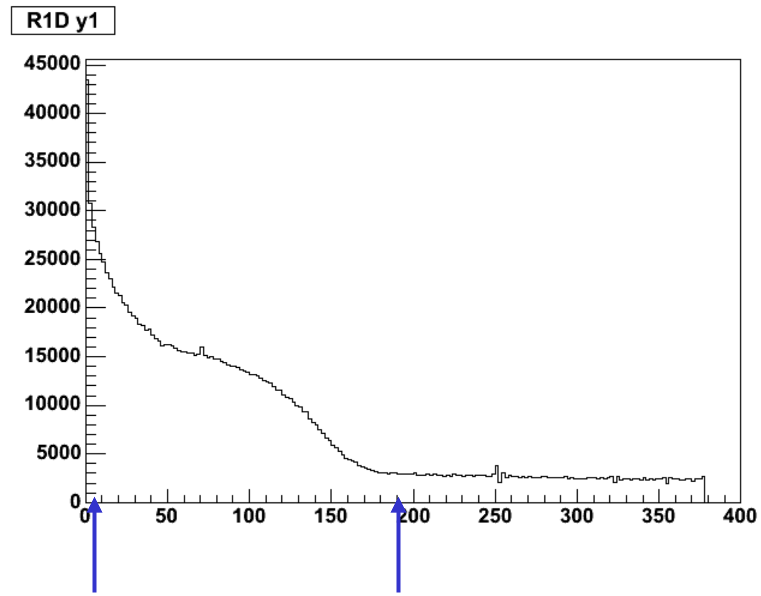
D| x_1-x_2| < 2 strips and D| y_1-y_2| < 2 strips



Fiducial and dE/dx cuts



Strips in x used for reconstruction



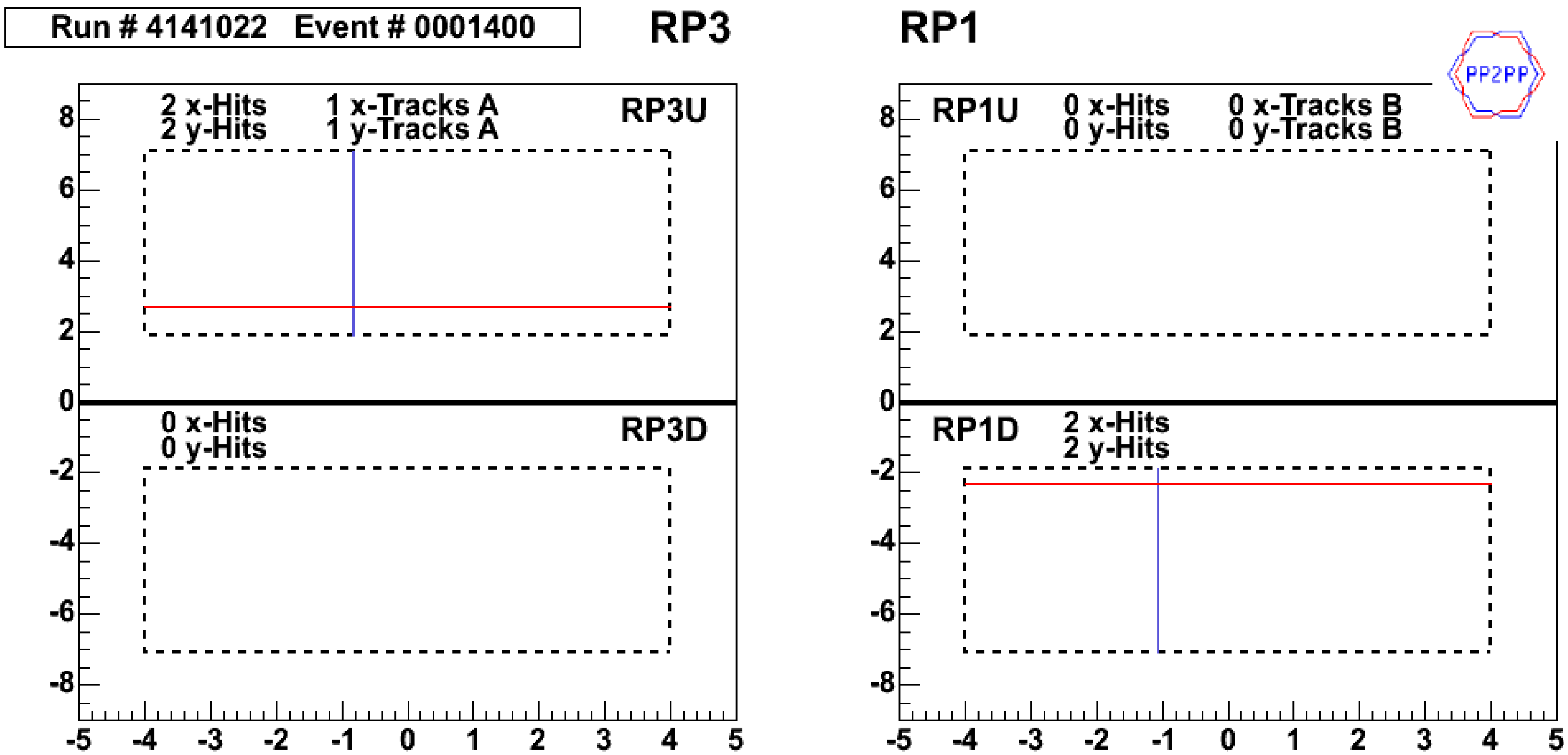
Strips in y used for reconstruction

Hit selection

1. Pedestal value, pedestal width (σ) and dead channels, only six, were determined;
2. Valid hit, single strip, has dE/dx > 5σ above the pedestal;
3. Cluster size is ≤ 5 consecutive strips above pedestal cut;
4. Valid hit in the Si plane for event reconstruction:
   - is a cluster whose dE/dx > 20 ADC counts above pedestal and
   - is within fiducial area of the detector (slide);
   - has for a y-plane y > 0.2mm from the edge of the detector.
5. Coordinate for x and y formed from adjacent hits in Sin for each Roman Pot

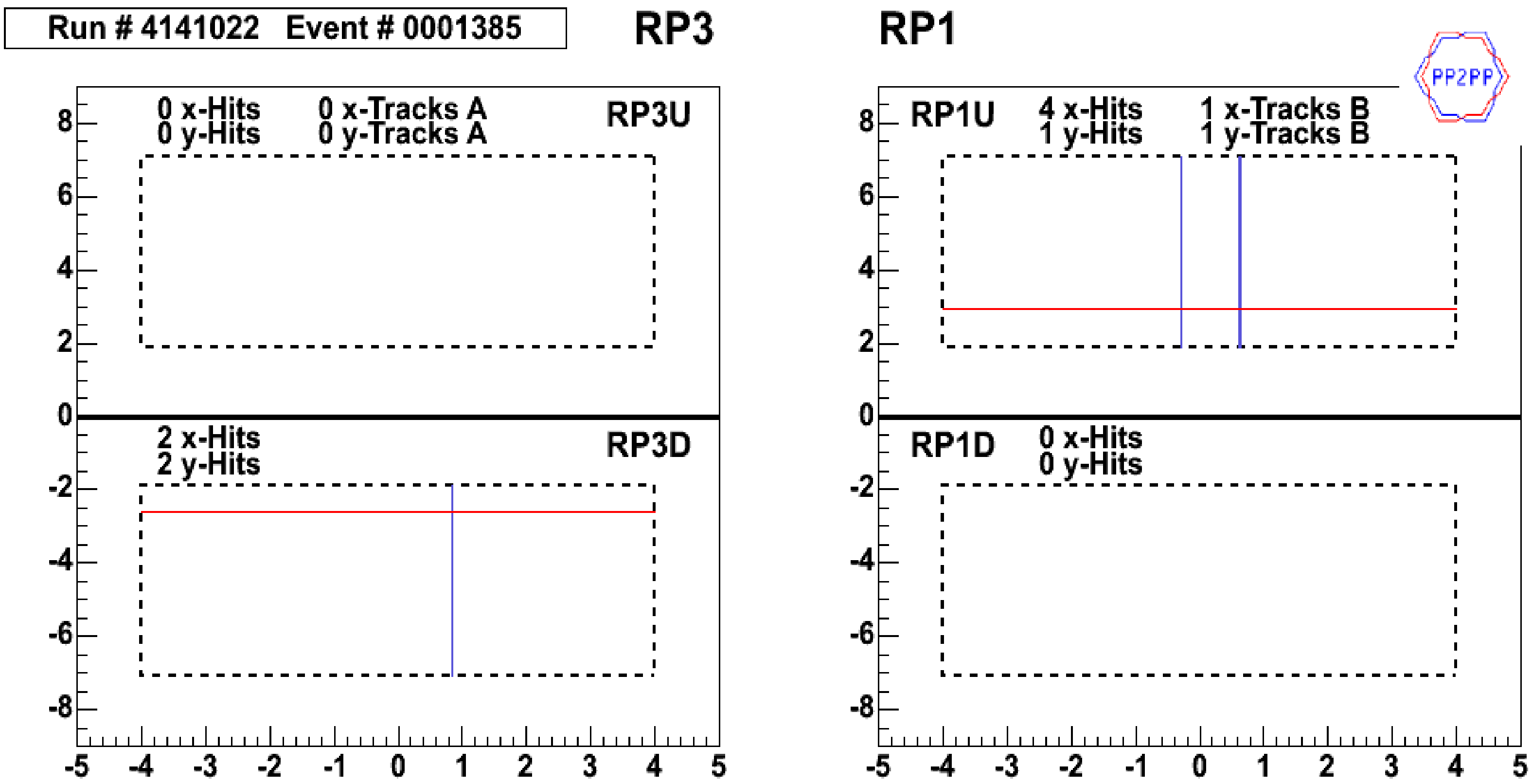
Elastic Events

Display Dave Morse



Background Events

Display Dave Morse

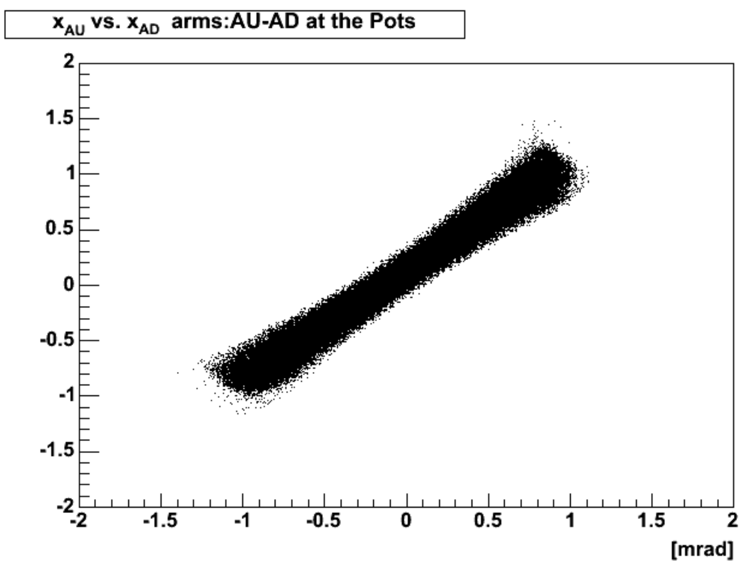


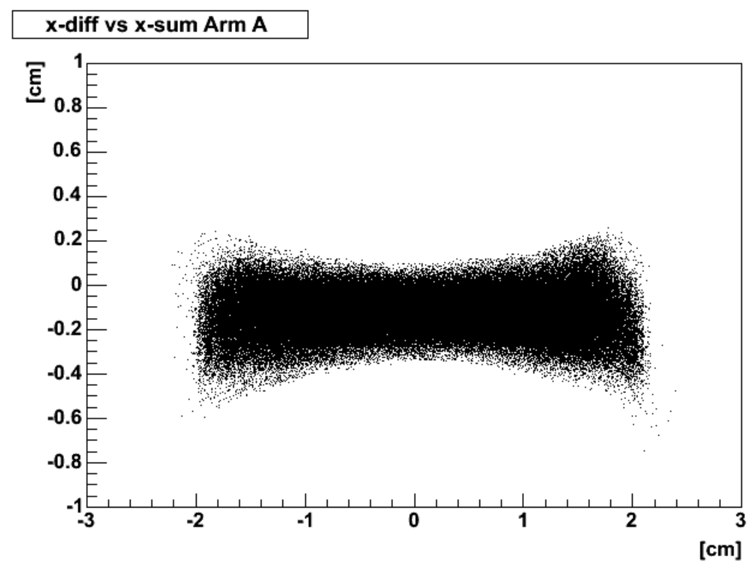
Elastic Event Selection I

Up Down Corerlations

Use the correlation between coordinates from two opposite RPs

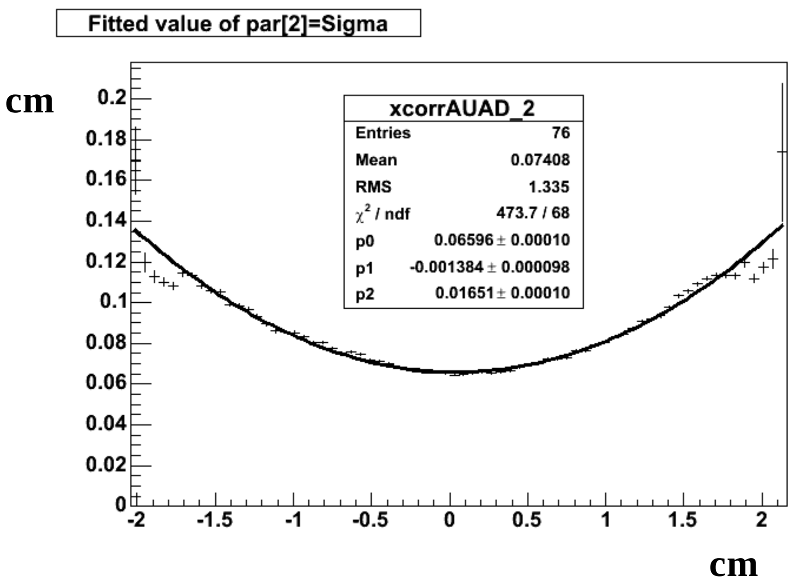
(RP1U – RP3D) or (RP1D – RP3U) to define candidate tracks.





Elastic Event Selection II

Use natural widths of the distributions - σ(x1-x2) vs (x1+x2)



Elastic Event Selection III

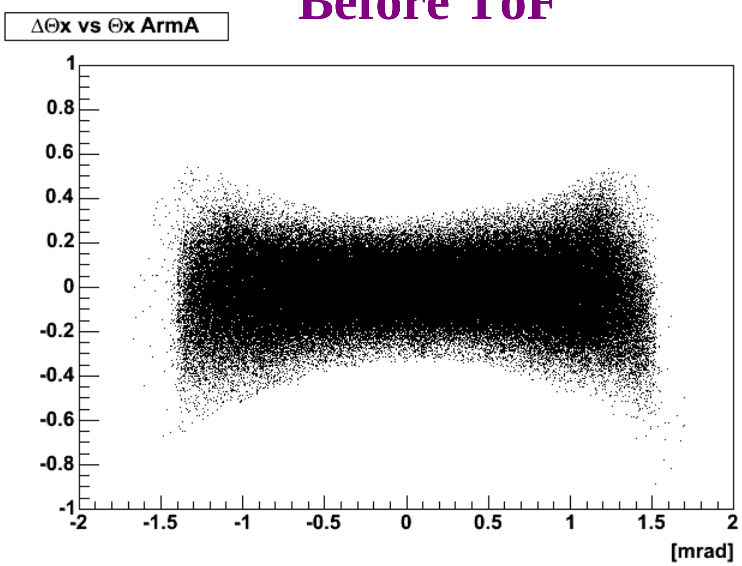
After finding matching hits in x and y:

- Choose events with one track in x and one track in y and $\geq$ 6hits.
- Veto on the Sc signal in the opposite arm, TDC cut.
- Choose collinear tracks within 3σ in angles.
- Plot dN/dt and calculate asymmetries.

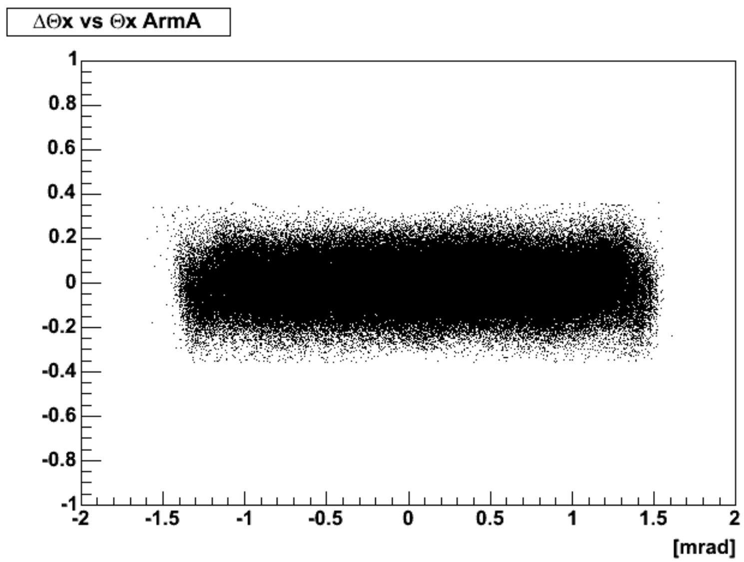
Calculation of Scattering Angle

1. Using matched hits scattering angels can be calculated.
2. Use transport and and average (x_0, y_0) and beam angles obtained from vectors reconstructed using all eight RPs.
3. Make z-vertex correction using ToF.

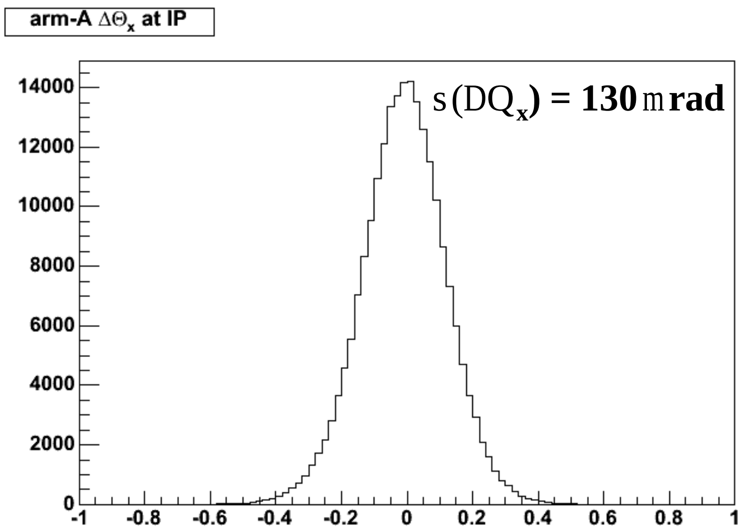
Before ToF

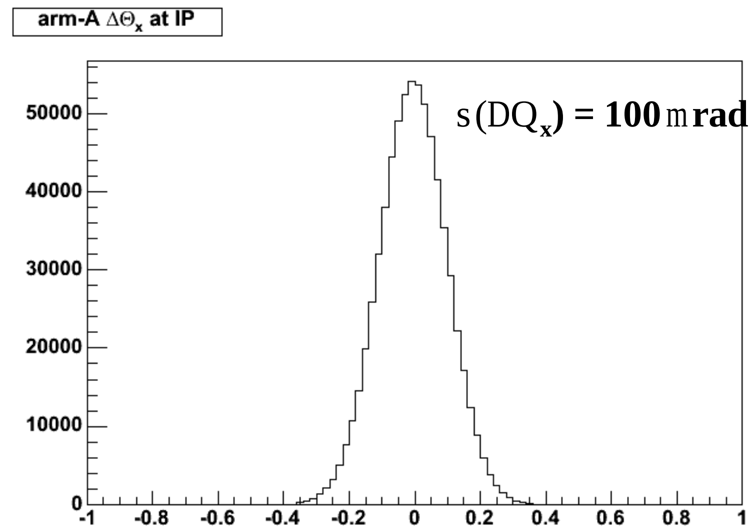


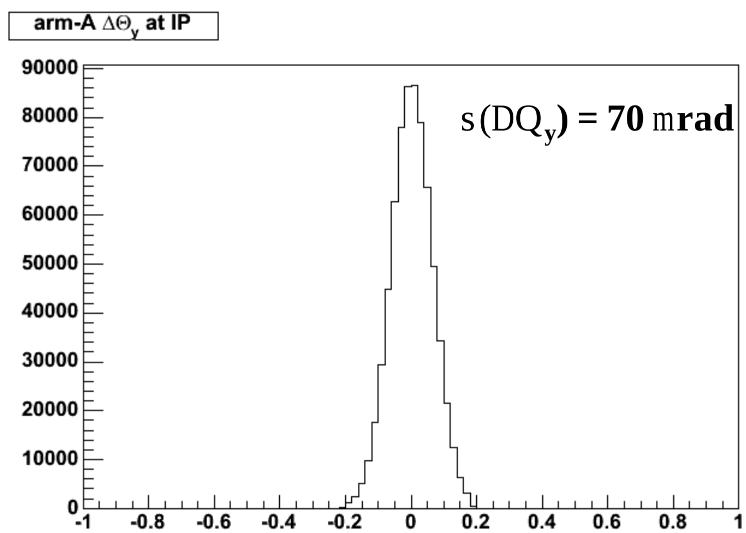
After ToF



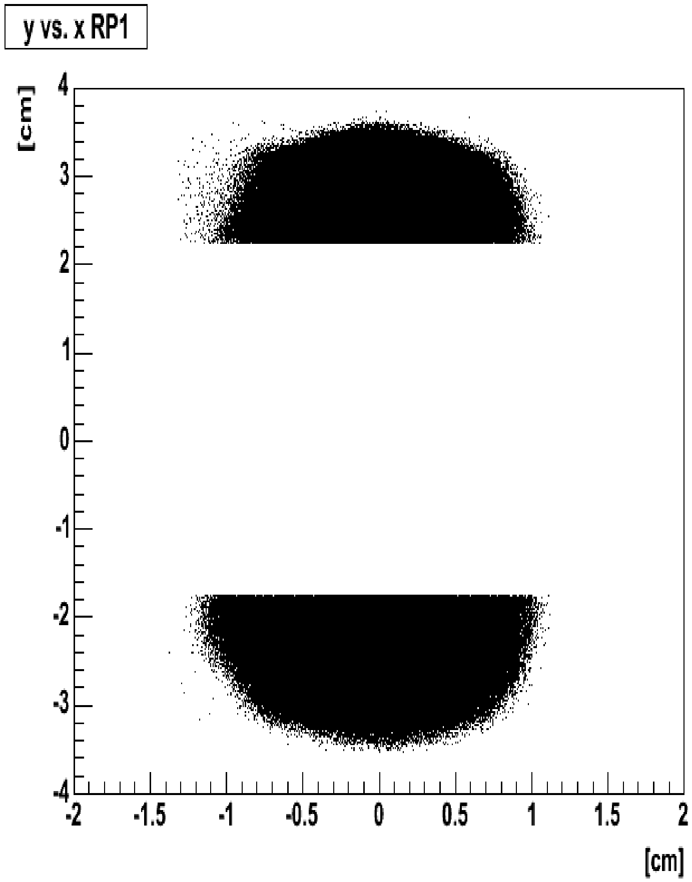
Collinearity: $\Delta\Theta_x$ before and after z-correction, and $\Delta\Theta_y$

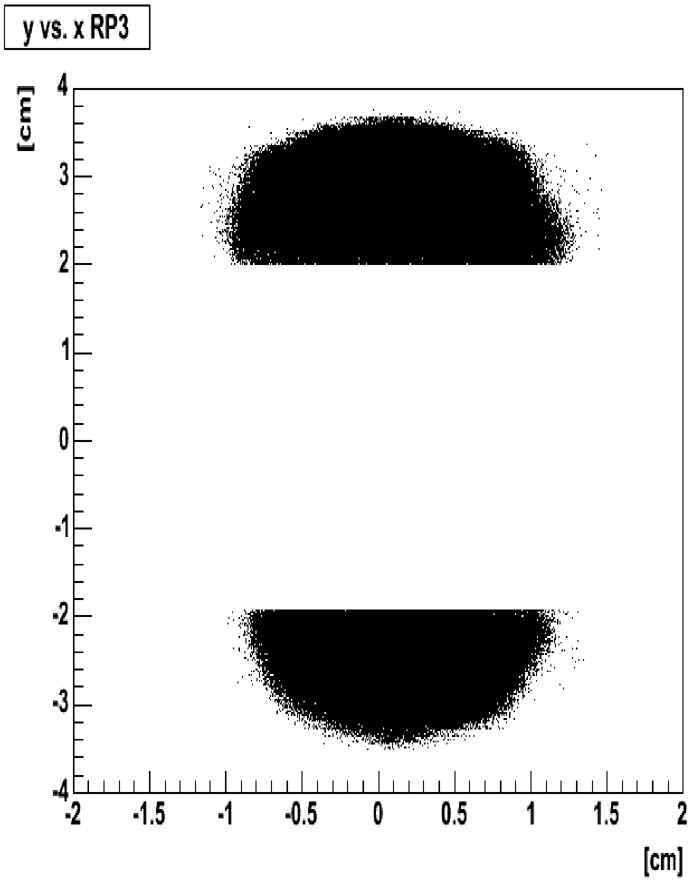




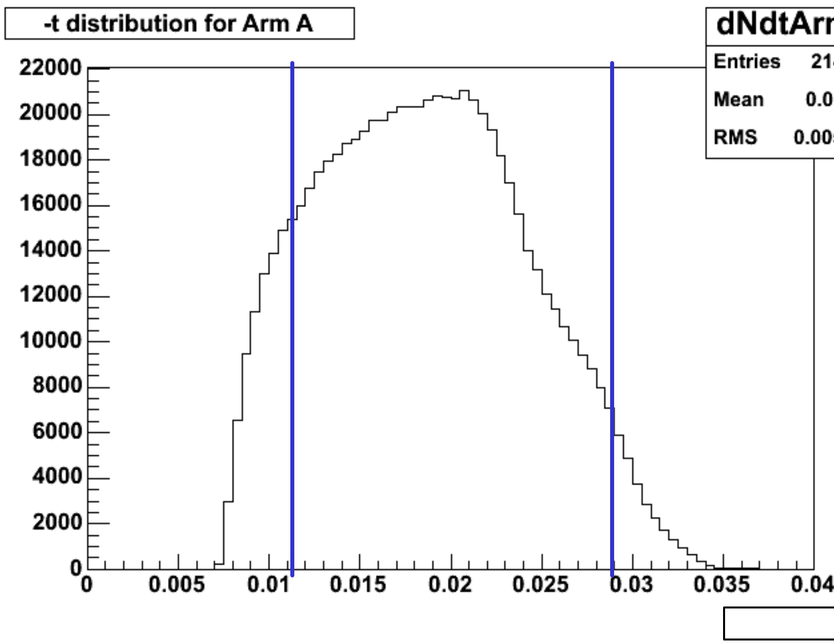


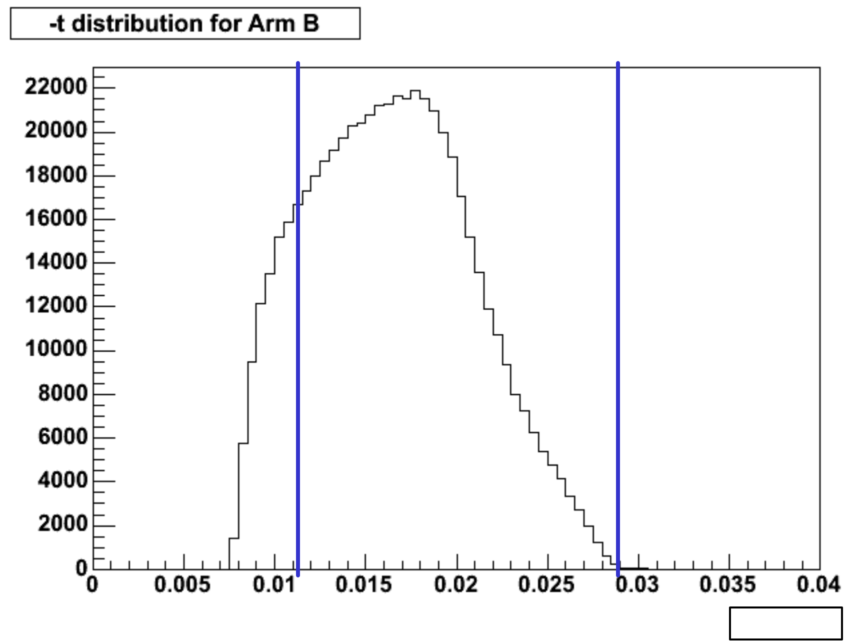
Elastic Events after Cuts: (x,y) Disrtibutions





dN/dt





Useful t-interval [0.011,0.029] (Gev/c)^2

Event Yields after Cuts

DESCRIPTION	# Events
All Events	**3,699k**
Elastic trigger	**3,598k**
Events with hits in Si fid. area (≥ 6 hits/event)	**1,816k**
Candidate elastic events (at least one track using x,y correlations) Arm A + B	**1,295k**
Collinear elastic events: 3σ cut in ($\Delta\theta_x$, $\Delta\theta_y$) one track in Arm A+B only	**1,254k**
Elastic events used for spin analysis, t-cut	**1,218k**
Candidate elastic events arm A	**716k**
Candidate elastic events arm B	**579k**
Collinear events: 3σ cut in ($\Delta\theta_x$, $\Delta\theta_y$) arm A	**696k**
Collinear events: 3σ cut in ($\Delta\theta_x$, $\Delta\theta_y$) arm B	**558k**

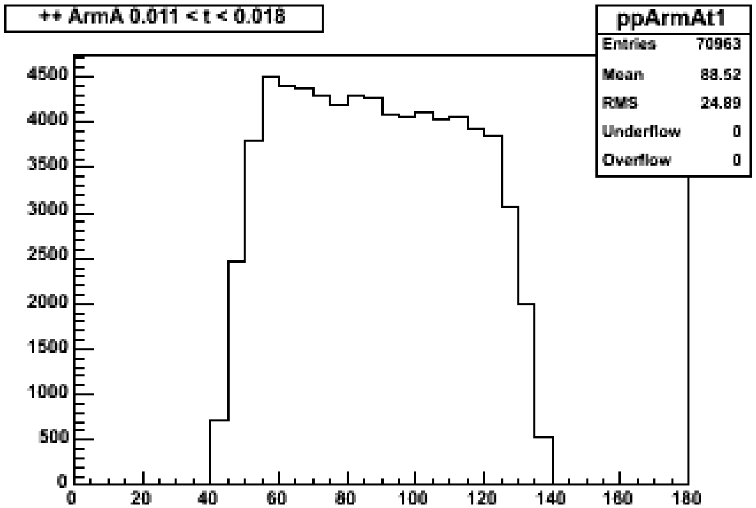
Determination of A_N

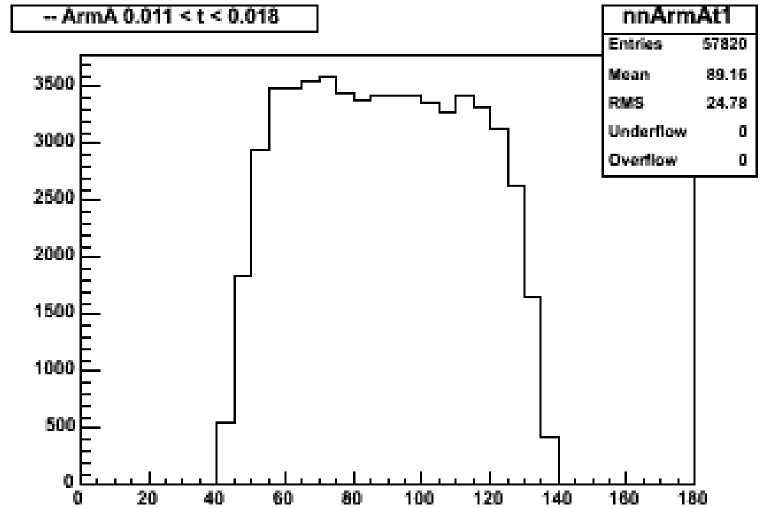
Use *Square-Root-Formula* to calculate raw and false asymmetries, since it cancel luminosity dependence. It uses ↑↑, ↓↓ and ↑↓, ↓↑ bunch combinations.

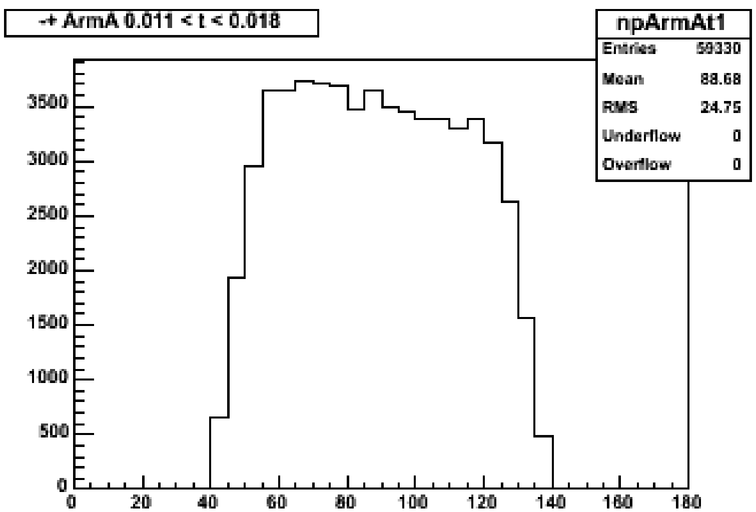
$$A_N(j) = \frac{1}{(P_1 + P_2)\cos j}\,\frac{\sqrt{N_L^{- -} N_R^{\text{— —}}} - \sqrt{N_R^{- -} N_L^{\text{— —}}}}{\sqrt{N_L^{- -} N_R^{\text{— —}}} + \sqrt{N_R^{- -} N_L^{\text{— —}}}}$$

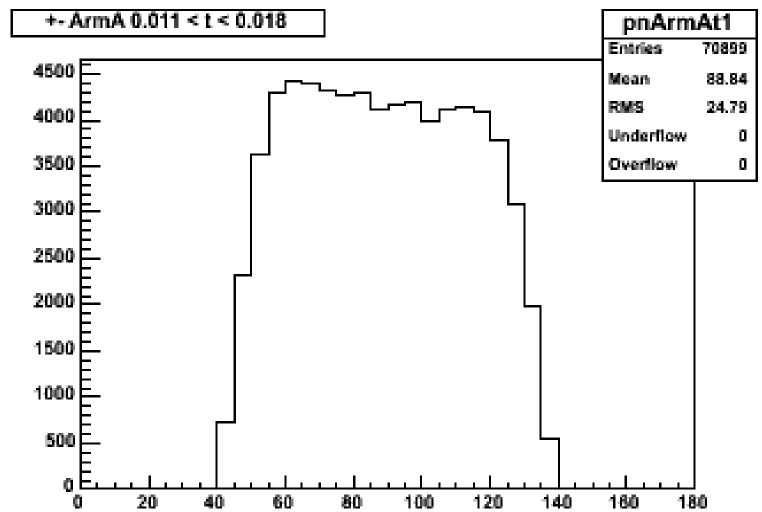
$$A_N(j) = \frac{1}{(P_1 + P_2)\cos j}\,\frac{\sqrt{N_L^{-\text{—}} N_R^{\text{—}-}} - \sqrt{N_R^{-\text{—}} N_L^{\text{—}-}}}{\sqrt{N_L^{-\text{—}} N_R^{\text{—}-}} + \sqrt{N_R^{-\text{—}} N_L^{\text{—}-}}}$$

Φ angle distributions for spin combinations



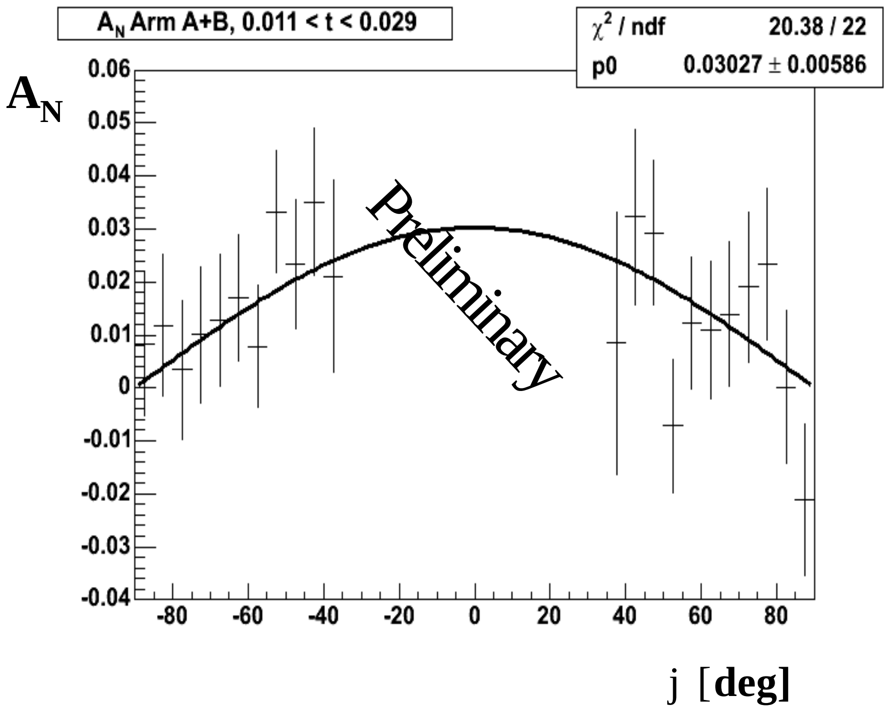


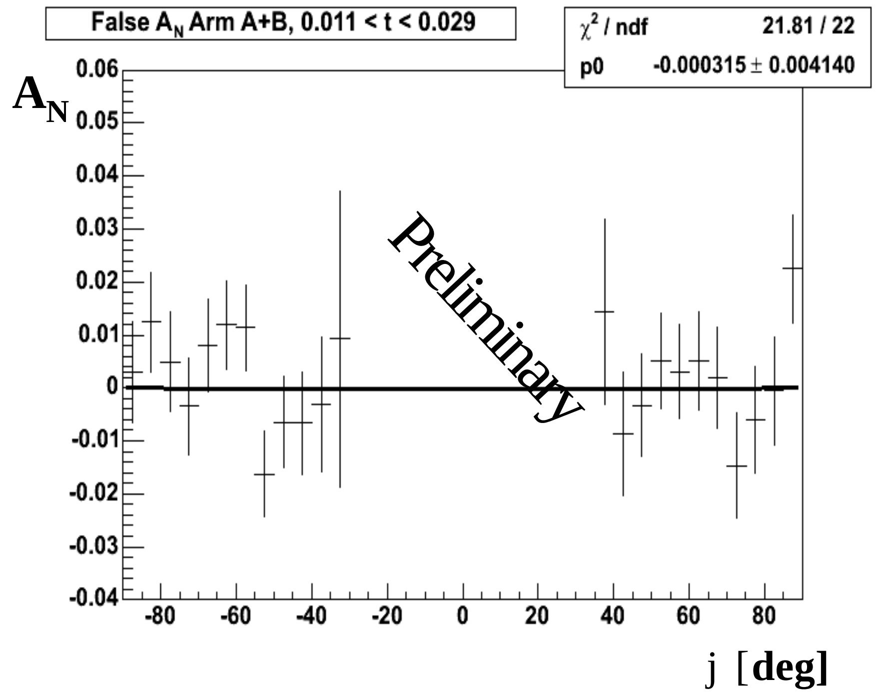




Preliminary Results: Full bin 0.011 < -t < 0.029 (GeV/c)^2

Fit A_N cos(j) dependence to obtain A_N



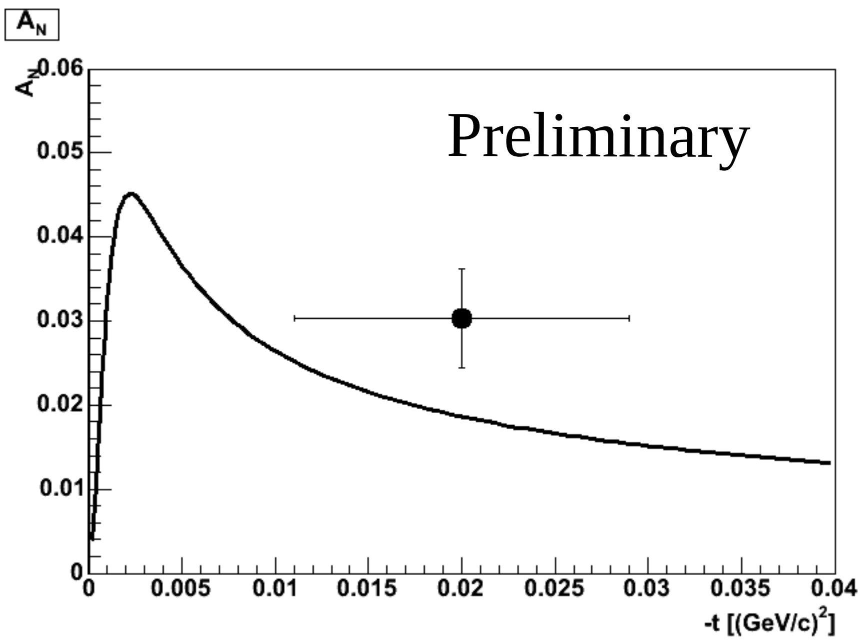


Results: $P_{Yellow} + P_{Blue} = 0.67$ and CNI curve

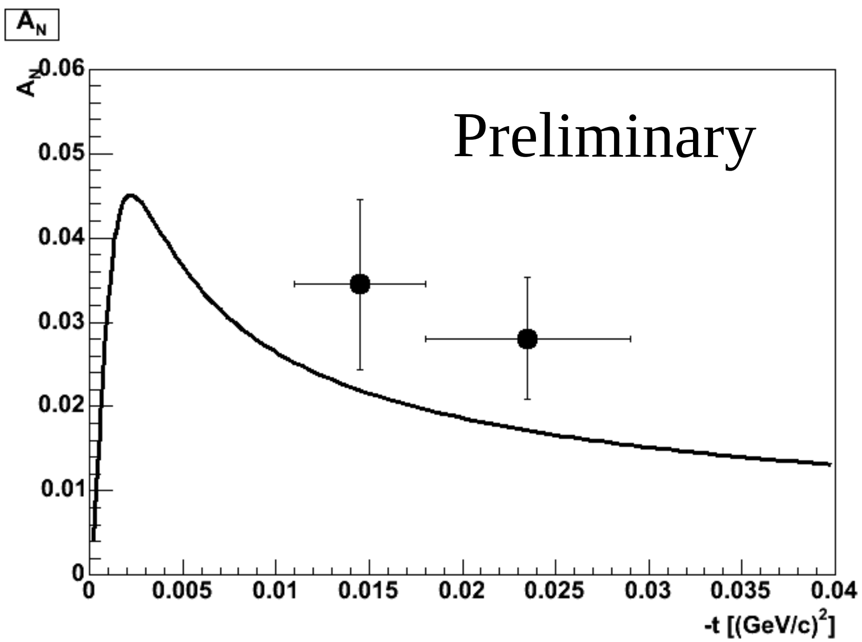
(σ_{tot}, ρ from world data, B from pp2pp result)

One point for the full

t-interval [0.011,0.029]



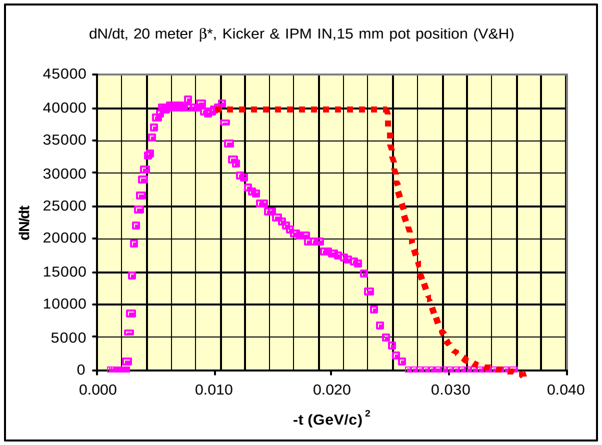
Two points for two half intervals



Note: $P_{Yellow} + P_{Blue} = 0.67$ can vary by ± 15% (a working number)

Future Possibility – Big Improvement

dN/dt

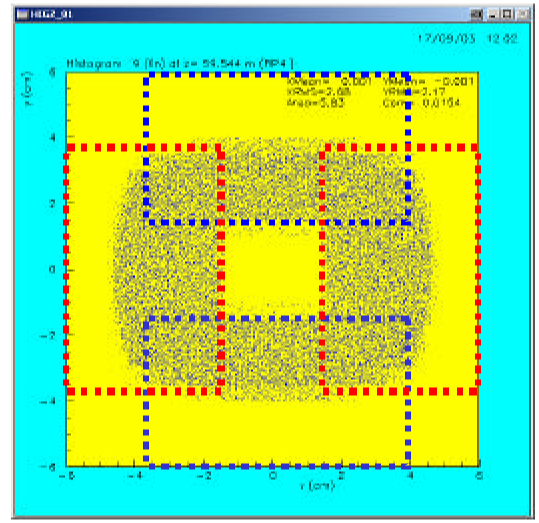


Full acceptance at Ös 200 GeV

Without IPM and kicker

With IPM and kicker

x-y



√s (GeV)	β*	|t|-range (Gev/c)^2	Typical errors
200	**20 m**	**0.003 < |t| < 0.02**	D**B = 0.3,** D s $_{\mathbf{tot}}$**= 2 – 3 mb** D r **= 0.007 and** D**A$_N$=0.004**
500	10 m	0.025 < |t| < 0.12	$\Delta B = 0.3$, $\Delta\sigma_{tot}$= 2 – 3 mb ΔA_N=0.004
Cost: $ 25k			

Summary

1. We have measured the single spin analyzing power A_N in polarized pp elastic scattering at $\sqrt{s}$ = 200 GeV in t-range [0.011,0.29] $(GeV/c)^2$.
2. The A_N is ≈ SD away from a CNI curve, which does not have hadronic spin flip amplitude.
3. We received preliminary interpretation of the result from Larry Trueman and Boris Kopeliovich, to be discussed at the RSC meeting this Thursday.

RHIC is a great and unique place to do this physics!